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Results of a Simulator Investigation of Control System and Display Variations for an Attack Helicopter Mission

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Abstract

A piloted simulator experiment designed to assess the effects on overall system performance and pilot workload of variations in control system characteristics and display format and logic for a nighttime attack helicopter mission is described. The simulation facility provided a representation of a helmet-mounted display image consisting of flight-control and fire-control symbology superimposed on the background video from a simulated forward-looking infrared sensor. Control systems ranging from the baseline stability and control augmentation system to various hover augmentation schemes were investigated together with variations in the format and logic of the superimposed symbology. Selected control system and display failures were also simulated. The results of the experiment indicate that the baseline control/display system is unsatisfactory without improvement for the evaluation task which included a hovering target search and acquisition. Significant improvements in pilot rating were achieved by both control system and display variations.

Notation

A_{1_s} Lateral swashplate angle, deg

B_{1_s} Longitudinal swashplate angle, deg

CDX Longitudinal cyclic control director deflection, deg of arc

CDY Lateral cyclic control director deflection, deg of arc

CDZ Collective control director deflection, deg of arc

FOV Field of view

g Acceleration due to gravity, 9.81 m/sec^2

h Altitude above ground level, m

$\dot{h}$ Instantaneous vertical speed, m/sec

$K_{(\ )}$ Control director gain, deg/( )

NOE Nap of the Earth

PR Cooper-Harper pilot rating

s Laplace operator, $\sigma \pm j\omega$

UK( ) Control system gain, deg/( )

x Longitudinal position error, m

$\dot{x}$ Longitudinal inertial velocity, m/sec

$\hat{\dot{x}}$ Estimate of $\dot{x}$, m/sec

y Lateral position error, m

$\dot{y}$ Lateral inertial velocity, m/sec

$\hat{\dot{y}}$ Estimate of $\dot{y}$, m/sec

Z_w Heave damping parameter, sec^{-1}

δ_a Pilot's lateral cyclic control position, cm

δ_c Pilot's collective control position, cm

δ_e Pilot's longitudinal cyclic control position, cm

δ_r Pilot's directional control position, cm

θ_0 Main rotor collective pitch, deg

θ_{TR} Tail rotor collective pitch, deg

Introduction

Investigations of methods by which highly maneuverable advanced helicopters can be made to function — with reasonable levels of pilot workload — as stable platforms for target designation or weapon delivery at night and under adverse weather conditions form a major area of research at the U.S. Army Aeromechanics Laboratory. Two candidate techniques under investigation are: (1) modifications to the helicopter's control system that alter the aircraft's response to pilot control inputs and to external inputs, such as turbulence; and (2) variations in the methods by which

critical information is displayed to the pilot in an attempt to reduce the effort required to interpret and respond to a given situation while still maintaining a satisfactory level of system performance. In support of this area of research, a piloted simulator experiment was designed and conducted to assess the effects on overall system performance and pilot workload of variations in control system characteristics and display format and logic for a nighttime attack helicopter mission. This paper describes the experimental design and conduct and presents the major results and conclusions of that investigation.

The requirement that military rotary-wing aircraft operations be conducted at night and under other conditions of limited visibility has given impetus to research programs designed to investigate interactions of the elements of the pilot-aircraft-display system for various helicopter missions. Control/display handling qualities research, both generic and specific in nature has been applied to particular VTOL aircraft tasks; Reference 1 presents a survey of the results of investigations of the helicopter decelerating instrument approach task, and Reference 2 describes the results of research programs addressing the problem of VTOL aircraft hover and low-speed operations during reduced visibility conditions. The investigation described herein extends the experimental approach found applicable to the tasks addressed by these references to the Army's requirement to conduct attack and scout helicopter missions at night and during conditions of limited visibility.

The task under consideration for this experiment consists of several elements of an attack helicopter mission conducted at night; specifically:

1. Low-speed, low-altitude flight

2. Deceleration to a hover

3. Precision hover

4. Unmask

5. Target search and acquisition

6. Remask

This demanding task is exacerbated by the hostile environment in which it is conducted. In addition to conditions of severely limited external visual cues, the mission is flown over terrain that is usually unfamiliar to the pilot, in unknown winds, in turbulence, and with a constant threat of detection by the enemy. To compensate for the lack of real-world visual cues, the pilot is provided with a limited

field of view (FOV) black-and-white video image of the outside world. Because of the limitations of this video image, a multitude of symbols designed to assist the pilot in navigation and control of flight are superimposed on the background imagery. Additional symbols are superimposed on the navigation and flight control symbology to provide the pilot with the information required to achieve his ultimate objective: successful weapon delivery. The difficulty of the piloting task, the hostile environment, and the complexity of the aircraft systems all contribute to the high pilot workload inherent in this attack helicopter mission. A primary purpose of this and similar research efforts is to investigate methods by which the pilot effort required for the task can be reduced without significantly degrading overall system performance.

Simulator and flight experiments addressing the Army problem of reducing the high workload inherent in the low-speed, low-altitude portion of the nighttime attack or scout helicopter mission have been conducted previously by the Army Avionics Research and Development Activity (AVRADA).[3] This AVRADA research concentrated on the pilot's display, which consists of flight symbology superimposed on the video output from a forward-looking infrared (FLIR) sensor; the combined imagery has been presented both on a panel-mounted display with a fixed FLIR sensor and on a helmet-mounted display (HMD) with the FLIR sensor slaved to the motions of the pilot's head. The HMD version of this concept has been adopted as a requirement for the Army's Advanced Attack Helicopter (AAH) Pilot Night Vision System (PNVS).[4] Preliminary simulations of a system similar to the PNVS conducted by AVRADA revealed that although no additional tasks, such as those related to target search and acquisition, were required of the pilot, a high workload condition existed during the bob-up maneuver in which the pilot attempted to maintain a precise hover position over the ground during vertical unmasking and remasking. As a result, it was recommended that the potential benefits of alterations in the dynamics of the hover symbology and the implementation of automatic hover augmentation in the aircraft control system be investigated. The design of the experiment described in this paper incorporated those recommendations into a more general investigation of control system and display effects on aircraft handling qualities for an attack helicopter mission that included a weapon delivery task.

Experiment Design

It was expected that several elements of the pilot-aircraft-display system would

interact to determine the workload required of the pilot to attain a given level of performance for the task in question. Accordingly, three sets of experimental variables were selected for investigation in the simulation program:

1. Control system: varying degrees of stability and control augmentation including control system failures

2. Display: variations in the format, that is, the location and physical characteristics of the individual symbols, and in the logic driving certain key symbols, which determines the dynamics of those symbols in response to pilot control and external inputs such as turbulence

3. Environment: variations in environmental conditions consisting of steady wind, wind shear, and turbulence.

Control Systems

For this experiment, the mathematical model of the unaugmented attack helicopter consisted of six-degree-of-freedom aircraft equations of motion which include a simplified representation of the aerodynamic forces and moments based on both computer-generated and flight-test data for the AAH. No rotor system dynamics were included. The details of the model are presented in Reference 5; the stability and control derivatives of the unaugmented helicopter for the hover condition are presented in Table 1. The stability and control augmentation systems (SCAS) that were investigated include two systems specific to the AAH and several hover augmentation system (HAS) concepts designed for the hover and low-speed portion of the mission. The actual implementation of these systems for the simulation is discussed in Reference 5.

The AAH SCAS in hover as implemented for this simulation consists of attitude and attitude rate stabilization, airspeed feedback, and control quickening in pitch and shaped angular rate feedback and control quickening in roll. The yaw SCAS comprises washed-out yaw rate damping augmentation and control quickening. The control quickening in all three axes provides the agility required for some NOE maneuvers. The AAH Attitude Hold feature removes the control quickening in the pitch and roll axes and adds a pseudo-heading-hold feature in yaw by appropriate filtering of the washed-out yaw rate feedback signal. Simplified block diagrams of these two control systems are included in Figures 1 through 4.

Three types of HAS were designed for this experiment, each providing the pilot

with a different form of horizontal velocity control through the cyclic stick:

1. HAS 1: inertial acceleration command, velocity hold (IACVH)

2. HAS 2: inertial velocity command (IVC)

3. HAS 3: inertial velocity command, position hold (IVCPH)

The two velocity command systems, HAS 2 and 3, were designed to provide good handling qualities based on the experimental data summarized in Reference 2. Specifically, the equivalent time-constant of the velocity response to cyclic stick was designed to be 2 sec in both the longitudinal and lateral axes. The control gearing was initially set to provide a steady-state response of 1.2 m/sec of velocity per cm (10 ft/sec/in.) of cyclic stick deflection, as is suggested by Reference 2; preliminary evaluations of these systems resulted in a doubling of the lateral control gearing to achieve a lateral velocity response of 2.4 m/sec/cm (20 ft/sec/in.) of lateral cyclic stick deflection in the steady state. HAS 1 was designed with the identical feedback structure as HAS 2, but with an integral-plus-proportional feedforward to provide steady-state acceleration responses of 0.6 m/sec^2/cm (5 ft/sec^2/in.) longitudinally and 1.2 m/sec^2/cm (10 ft/sec^2/in.) laterally. The approximate hover transfer functions describing the appropriate velocity responses for each of the HAS are summarized in Table 2. For all the HAS, the yaw axis is designed as a rate-command, heading-hold (RCHH) system with a 0.5-sec time-constant yaw rate response to pedal input and a steady-state yaw rate response of approximately 0.13 rad/sec/cm (0.34 rad/sec/in.) of pedal displacement. In hover, the yaw-rate-to-directional pedal transfer function for the RCHH system may be approximated as:

$$\frac{r}{\delta_r} = \left\{\frac{\theta_{TR}}{\delta_r}\right\} \cdot \frac{r}{\theta_{TR}}$$

$$\approx \left\{\frac{3.33(s + 2.0)}{s}\right\} \cdot \frac{-0.08\,s}{(s + 2.0)^2} - \text{rad/sec/cm}$$

Block diagrams of the three hover augmentation systems are presented in Figures 1 through 3.

Two vertical augmentation systems were also designed for this experiment, each of which provided the pilot with a 1-sec time-constant vertical rate response to collective stick input in the hover; the first system provides a pure altitude rate command (RC), the second a rate-command, altitude-hold (RCAH) feature. The control sensitivities were set to provide

a steady-state vertical velocity response to collective inputs of about 1.9 m/sec/cm (16 ft/sec/in.) in hover. The approximate transfer functions for vertical velocity response to collective inputs in the hover for the two vertical augmentation systems are:

$$\frac{\dot{h}}{\delta_c} = \left\{\frac{\theta_o}{\delta_c}\right\} \cdot \frac{\dot{h}}{\theta_o} \sim m/sec/cm$$

RC	$(1.34) \cdot \dfrac{1.39\,s}{s + 1.0}$
RCAH	$\left\{\dfrac{1.34(s + 1.0)}{s}\right\} \cdot \dfrac{1.39\,s}{(s + 1.0)^2}$

Figure 4 includes a block diagram of these vertical augmentation systems.

Dead zones are included in the integral feedforward paths for all the hover-vertical augmentation systems to prevent drift caused by the integration of inadvertent pilot control inputs; the size of the dead zones, ±0.25 cm (±0.1 in.), was selected to be large enough to prevent any noticeable drift effects even in turbulent conditions yet small enough so as not to affect adversely the system response to control inputs.

The generic characteristics of all the control systems investigated are summarized in Table 3. The control force characteristics remained the same for all control systems throughout the experiment; they are presented in Table 4.

In addition to an evaluation of the AAH control systems and various HAS concepts for the nighttime mission, the effects of degraded SCAS modes were also investigated. Specifically, total failures of each of the AAH SCAS axes — pitch, roll, and yaw — individually were simulated. Finally, a full SCAS failure, resulting in a controlled vehicle with the characteristics of the unaugmented attack helicopter was implemented. No attempt was made to simulate the effects of the failure transients; the evaluation pilot was given the aircraft in a trimmed condition with the selected failure state already in effect.

Displays

For the nighttime attack helicopter mission, one function of the pilot's display is to compensate for the lack of external visual cues. It has been demonstrated that a helmet-mounted display that consists only of a limited FOV FLIR image of the outside world is insufficient for the low-speed, low-altitude portion of the mission, and that superimposed flight-control

symbology can considerably enhance the usefulness of this particular display medium.[3] From the pilot's point of view, three display characteristics determine the suitability of a given set of superimposed symbology for a particular task:

1. Information content: Is the displayed information inadequate, sufficient, or excessive for the task?

2. Format: Do the location and physical characteristics of the individual symbols enhance or degrade the efficiency of information transfer?

3. Logic: Do the symbols accurately reflect aircraft status, and do they respond in an orderly fashion to pilot control inputs and external disturbances?

These sets of display characteristics formed the basis for the display variations considered in this experiment.

The baseline display format investigated[4] consists of four discrete display modes — cruise, transition, hover, and bob-up — that are selectable by the pilot. Reference 3 describes the operational requirements associated with each display mode as:

1. Cruise: high-speed level flight en route to the forward edge of the battle area

2. Transition: low-speed nap-of-the-earth maneuvers such as dash, quick stop, and sideward flight

3. Hover: stable hover with minimum drift

4. Bob-up: unmask and remask maneuvers over a selected ground position

The bob-up mode of the baseline format is depicted in Figure 5.

In order to explain more clearly the information content and details of the baseline symbology for all display modes, the symbols are divided into three categories: central (Fig. 6a), peripheral (Fig. 6b), and fire control symbology (Fig. 6c). The central symbology (Fig. 6a) changes as a result of the pilot's manual display mode switching; the characteristics of the four display modes are:

1. Cruise: velocity vector, cyclic director, and hover position symbols deleted

2. Transition: horizon line and hover position symbols deleted

3. Hover: horizon line deleted and hover position symbol fixed at center; increased velocity vector sensitivity compared to transition mode

4. Bob-up: horizon line deleted; hover mode velocity vector sensitivity retained

The peripheral symbology (Fig. 6b) is invariant with display mode. The launch constraints symbol (Fig. 6c) only appears when the bob-up display mode is selected by the pilot.

The display variations investigated in this experiment consist of perturbations to the hover and bob-up modes of this baseline format in the areas of information content, format, and logic.

Variations in information content were mechanized in the form of display failures. They were:

1. FLIR failure — loss of background video

2. Loss of velocity vector symbol

3. Loss of cyclic director symbol

4. Loss of velocity vector and cyclic director symbols

5. Loss of all hover symbology — velocity vector, cyclic director, and hover position symbols inactive

To explore the effects of variations in the display format, an alternative format, consisting of potential improvements to the baseline format, was implemented (Fig. 7). A possible deficiency in the baseline format was judged to be the separation of the horizontal status and command information (Fig. 6a) from the vertical status information located on the right side of the display (Fig. 6b); concentration on the central symbology could result in degraded altitude tracking performance because of (1) the lack of vertical-horizontal information integration, (2) the incompatibility of the location of the vertical information with the location of the pilot's primary vertical controller (the collective pitch control) located on the pilot's left side, and (3) the lack of vertical command information. The first of these possible deficiencies was not addressed in this experiment. As a potential solution to the latter two deficiencies, the alternative format includes the radar altitude information on the left-hand side and, in lieu of a rate-of-climb indicator, a collective control director driven by blended altitude and altitude rate information which, when positioned on the

desired value of displayed altitude by the pilot's collective control inputs, causes the aircraft to reach and maintain that altitude. The expression for the collective director logic is:

$$CDZ = K_h(h - 100) + K_{\dot{h}}\dot{h}$$

where the gain K_h is selected to provide a scaling identical to that of the radar altitude thermometer, and the gain ratio $K_h/K_{\dot{h}}$ is set equal to the value of $-Z_w$ for the unaugmented aircraft in the hover, approximately $0.3 \ sec^{-1}$. This format also includes a horizon line, which remains on the display in all four modes to provide a compelling display of aircraft attitude in hover, and an analog display of low-range airspeed, presented in 20-knot increments from -20 to +60 knots.

Possible display deficiencies associated with the logic driving the central hover symbology were also identified; as a result, solution to the following display-related problems were devised and tested:

1. Inaccurate estimates of aircraft inertial velocity

2. Difficulty in control of the hover symbology

3. Loss of valid displayed hover position error information for large excursions from the designated hover area

For an aircraft neither equipped with an inertial navigation system nor provided with data from an external guidance system, estimates of inertial velocity and position must be derived from available on-board sensors. The concept adopted for this experiment requires inputs from a Doppler radar, attitude gyros, and linear accelerometers. Low-frequency Doppler drift velocities are blended with higher frequency estimates of inertial velocity based on approximate values of inertial acceleration in an effort to provide accurate, noise-free estimates of inertial velocity in the horizontal plane. A variation on this concept, introduced in Reference 3, requires no linear accelerometer input; preliminary evaluation of the Reference 3 implementation for this experiment revealed dynamic inaccuracies of the estimated velocity in response both to control inputs and to gusts. Both methods were implemented for comparison in this experiment. The details of both versions of the complementary filter logic used to derive the velocity estimates are presented in the Appendix.

The cyclic director symbol (Fig. 6a) is used by the pilot in the bob-up display mode to reach and maintain a precision hover over a designated position on the

ground. The expressions that relate the position of the director symbol to the location of the hover position symbol on the display are:

$$CDX = K_\theta \left[\frac{s}{s + (1/T_\theta)} \right] \theta + K_{\dot{x}}\hat{\dot{x}} + K_x x$$

$$CDY = K_\phi \left[\frac{s}{s + (1/T_\phi)} \right] \phi + K_{\dot{y}}\hat{\dot{y}} + K_y y$$

The values of the cyclic control director gains and time constants are presented in Table 5. Preliminary analyses of the response of CDX and CDY to longitudinal and lateral cyclic stick inputs in hover with the baseline SCAS engaged indicated that with the display gains presented in Reference 3 some difficulty would be experienced by the pilot in attempting to null the difference between these two symbols in a continuous fashion. Specifically, the open-loop response of CDX and CDY to cyclic inputs with the nominal display gains is a double integration (K/s^2) for much of the region of expected crossover. According to classical manual control theory (Ref. 6 for example), the controlled element should be K/s-like in that particular frequency region for ease of control and good closed-loop characteristics. As a result, an alternative set of display gains was synthesized to achieve this design goal; in general, different display gains were required for the various control systems implemented. As an example of the differences in control director response to control inputs caused by the selection of display gains, consider the response of CDX to longitudinal cyclic stick in hover. With the baseline SCAS engaged and the Reference 3 display gains in effect, the transfer function CDX/δ_0 may be approximated as:

$$K_1 \frac{(s + 1.24)(s + 1.47)}{(s + 0.15)^2 [s^2 + 2(0.75)(1.62)s + (1.62)^2]}$$

In contrast, with the alternative set of display gains, the same transfer function may be approximated as:

$$K_2 \frac{(s + 0.3)(s + 1.24)}{(s + 0.15)^2 [s^2 + 2(0.75)(1.62)s + (1.62)^2]}$$

The effect of moving the transfer function zero from 1.47 to 0.3 by changing display gain ratios is to create an area of K/s-like response in a frequency range from approximately 0.3 to 1.5 rad/sec. With the

Reference 3 gains, a K/s^2-like response occurs in this same frequency range. The values of the alternative gain parameters used for this experiment are included in Table 5.

A final possible deficiency of the display logic concerned the relatively high sensitivity of the hover position symbol. With the baseline display gains,[3] an excursion of 10 m (33 ft), less than the rotor diameter of the simulated helicopter, from the designated hover position will cause the hover position symbol to reach its display limit. Accordingly a nonlinear scaling technique was devised for this particular symbol which allows its sensitivity to be relatively high near the hover position but reduces the scale factor with increasing distance from the designated hover position. The alternative scale factors are expressed as:

$$K_x^* = \frac{K_x}{(d/c_1) + 1}$$

and

$$K_y^* = \frac{K_y}{(d/c_1) + 1}$$

where

c_1 = the display limit, in this case 15° of arc, divided by the desired hover position scale factor, K_x or K_y.

d = current horizontal distance to the designated hover point.

In summary, the investigation of these three general areas of interest resulted in the following three basic display variations:

1. H_0 — Baseline display format (Fig. 5)
   Reference 3 inertial velocity estimator (Appendix)
   Reference 3 hover symbology scaling (Table 5)

2. H_1 — Baseline display format
   Revised inertial velocity estimator (Appendix)
   Alternative hover symbology scaling (Table 5)
   Five display failure modes

3. S_1 — Alternative display format (Fig. 7)
   H_1 velocity estimator and hover symbology scaling

Environment

In order to provide a more realistic environment for the simulation and to assess the effects of external disturbances,

a model of low-altitude wind and turbulence was implemented for the simulation.[5] Two levels of disturbances were investigated: (1) Calm, that is, no wind or turbulence, and (2) moderate, consisting of a 10-knot steady wind at the nominal altitude, a moderate wind shear with altitude varying from 7 knots at 6 m (20 ft) to 14 knots at 61 m (200 ft), and 2-knot rms vertical and 4-knot rms horizontal gusts.

Conduct of the Experiment

The experiment was conducted on the Ames six-degree-of-freedom moving-base simulator facility, designated S.01, with the simulator cab modified to include a typical helicopter instrument panel and controllers (Fig. 8).

A key element of the simulation was the representation of a helmet-mounted display (HMD) image presented to the pilot on a panel-mounted TV monitor located so as to reproduce the actual HMD field of view characteristics: 30 vertical by 40 horizontal degrees of arc subtended at the pilot's eye (Fig. 9). The black and white image consisted of flight-control and fire-control symbology superimposed on the video from a simulated forward-looking infrared (FLIR) sensor mounted on the chin of the aircraft. The simulated FLIR imagery was derived from the camera and terrain board visual system; the scaled terrain used for this experiment is a 400:1 model representative of the Army's Ft. Hunter-Liggett facility.

Three pilots served as evaluation pilots for the experiment:

1. Pilot A: Army experimental test pilot with 3,165 flight hours, 2,450 of which were in rotary wing aircraft (~90 evaluations)

2. Pilot B: Experimental test pilot with 4,800 flight hours, 2,7 ° of which were in rotary wing aircraft (~12 evaluations)

3. Pilot C: NASA aerospace engineer and pilot with 7,700 flight hours, 1,160 of which were in rotary wing aircraft (~30 evaluations)

The evaluation task for this investigation consisted of several segments of the primary attack helicopter mission. These segments and the corresponding display modes follow:

1. Accelerate to an airspeed (V) of 40 knots at 100 ft above ground level (AGL). (CRUISE)

2. Descend to 50 ft AGL and decelerate to a hover near a designated point on the terrain. (TRANSITION)

3. Hover between 0-50 ft AGL. (HOVER)

4. Bob-up to 100 ft AGL over designated hover position. (BOB-UP)

5. Conduct target search in azimuth; when target designated, bring target within the missile launch constraints and simulate missile launch. (BOB-UP)

6. Descend to original hover position. (BOB-UP)

7. Accelerate to V ≈ 40 knots and depart the area. (TRANSITION)

Most of the evaluations were performed for an abbreviated task composed of segments (3)-(6) above. Each evaluation consisted of two runs of either the full mission or the hover and bob-up task. Data collected for each run included system performance data, such as hover position accuracy and attitude and velocity excursions, and the pilot physical workload data in the form of control activities. At the end of each evaluation the pilot was asked to assign a numerical Cooper-Harper pilot rating[7] to the task from a scale (shown in Fig. 10) and to provide commentary, based on a pilot commentary guide, to assist the experimenter in identifying the areas that most heavily influenced the rating. No additional tasks were required of the pilot nor were other tasks considered in the evaluation.

Results

The results of this experiment, based on an analysis of the pilot evaluation data, are discussed below in the three general categories of experimental variables selected in the design of the experiment: control system, display, and turbulence effects. This section concludes with a short discussion of task effects revealed by a comparison of the full mission with the hover and bob-up task. In this section, the intended use of averaged pilot ratings is as a device to indicate general trends; the statistical validity of this technique is not implied. The individual pilot's ratings are included to show the range of data for each configuration.

Control System Effects

Figure 11 presents the pilot rating results for the hover and bob-up task with the H_1 display as a function of control system type. The AAH control systems, SCAS and Attitude Hold, in general exhibit Level 2 handling qualities for this task.

Under calm conditions, the hover augmentation systems improve the ratings into the Level 1 region; however, with the level of wind and turbulence simulated, augmentation of the vertical axis is required to achieve Level 1 handling qualities.

The rather large variation in ratings given by Pilots A and C to the less sophisticated control systems can, in part, be attributed to the different techniques applied to the same task by the two pilots. Based on a comparison of hover performance data, Pilot A tended to be less aggressive than Pilot C, indicated by smaller values of rms control motions, appeared to concentrate more on horizontal position control than on precise altitude control, and was satisfied to perform the bob-up and weapon delivery portions of the task one step at a time. In contrast, Pilot C in general used larger rms control motions in all axes, achieved smaller altitude errors but larger horizontal position errors than Pilot A, and attempted to perform the bob-up and weapon delivery portion of the task as an integrated, multi-axis task in order to minimize exposure time.

Pilot C's ratings and commentary reflect an inability to perform the task adequately in turbulence without both horizontal velocity and vertical augmentation:

SCAS/H_1 – Pilot C: Difficult hover position control caused a breakdown in scan pattern and some overcontrol in height. (PR = 7)

Attitude Hold/H_1 – Pilot C: I tried to do the bob-up by climbing and yawing at the same time and still trying to hold the hover position and got a little off. I probably shouldn't have tried it with this flight control system. Overcontrol in height, primarily. The scan pattern is still a problem when one thing gets away from you. Adequate performance not attainable because of height control. (PR = 7)

HAS 2/H_1 – Pilot C: I used a combination heading change and altitude change to bob-up with some overcontrol in altitude. Target acquisition delayed because I got sidetracked in controlling altitude. Turbulence makes height control more of a workload item. (PR = 6)

Altitude control in turbulence was also a major factor in Pilot A's ratings of these same configurations although, in his judgment, adequate performance was achieved:

SCAS/H_1 – Pilot A: It takes real pilot attention to maintain a precise altitude. (PR = 5)

Attitude Hold/H_1 – Pilot A: No problem in bob-up and target acquisition. Some sluggishness in the controls. The only real problem I had was in altitude control. I was continually overshooting with the collective inputs but with the sensitivity of the display I was able to divide my attention a little better in getting back to the hover spot rather than having to fix my attention on the center (of the display). (PR = 4)

HAS 2/H_1 – Pilot A: Vertical axis required quite a bit of attention. (PR = 4)

With the addition of vertical augmentation, Pilot C judged the system to be satisfactory without improvement in turbulence:

HAS 2A/H_1 – Pilot C: Marked improvement, like night and day. Display and control system were compatible. Minimum of altitude overcontrol. Bobbing-up, target search, acquisition, and firing all were short and precise. A fairly high workload task but this is one of the better systems I've seen. (PR = 3)

Figure 12 demonstrates the effects on pilot rating of control system failures. A full failure of the roll SCAS does not have a significant effect on the handling qualities; however, failures of the pitch or yaw SCAS axes result in significantly degraded handling qualities for the task.

Display Effects

Figures 13 and 14 show the effects of display logic and format on pilot rating for the SCAS and Attitude Hold control systems, respectively. A general improvement in pilot rating occurs as a result of the alterations to the velocity vector logic and central hover symbology scaling, which transforms the H_0 display to the H_1 display; however, no further improvement is achieved by the display format variations represented by the S_1 display.

The PR of 9 assigned to the SCAS/H_0 combination in turbulence by Pilot A (Fig. 13) came as a result of the pilot's inability to reduce a large horizontal position error which was inadvertently allowed to build up:

SCAS/H_0 – Pilot A: I really had to fight to keep up with hover position control; I was continually overshooting. I don't think I ever did reach a precise hover. At one time, the location of the hover (position symbol) went to the full extreme of the display. I was ±75-100 ft on altitude. I was spending so much time

trying to get back to the hover point that I would only cross-check the altitude every so often and make a small (collective control) change. (PR = 9)

With the modified dynamics of the H_1 display, horizontal position control with the SCAS continued to demand significant pilot effort, but Pilot A judged system performance to be adequate in turbulence.

SCAS/H_1 – Pilot A: The sensitivity of the cyclic director seemed to be fairly high compared to the reaction of the aircraft itself. I felt at times as though I was chasing the ball in order to get back (to the hover position). (PR = 5)

Figure 15 demonstrates the effects of the display failures investigated in this experiment. A general degradation of pilot rating occurs as a result of these failures with the exception of the FLIR failure simulated by a loss of the background video; pilot commentary indicates that the resulting improvement in display contrast allowed a more precise control of horizontal position and improved performance in target acquisition, hence the improvement in rating. With the "best" control system for the task in turbulence, HAS 2A (see Fig. 11), the effects of the display failures evident with the SCAS were considerably reduced. Even with a full failure of the hover symbology, the handling qualities of the more highly augmented system did not degrade to Level 3; in contrast, the failure of the velocity vector and cyclic director symbols yielded Level 3 handling qualities with the baseline SCAS.

With the velocity vector failure in effect, no explicit indication of translational rate was available to the pilots; however, cyclic director information continued to be provided:

SCAS – Pilot A: The lack of velocity information really hurt me in hover mode. I was trying to use my airspeed indicator to give me at least fore-and-aft positioning information; the moving box in bob-up provides a secondary velocity cue over the ground. (PR = 5)

HAS 2A – Pilot A: A little problem in the hover phase, but by just switching to the bob-up display, the motion of the box gave me a pretty good velocity cue. (PR = 4)

Without the cyclic director, no explicit guidance for hover position control was provided to the pilots:

SCAS – Pilot A: I was completely overcontrolling, bypassing my desired hover point. By the time the velocity vector would generate, I would have to make another

input in the opposite direction. The (director) information is really required. (PR = 6)

SCAS – Pilot C: Heading and altitude control went to pot during bob-up because of a saturation in pilot workload required for positioning. (PR = 7)

With the hover and vertical augmentation system, the effects of the same display failure were not as evident:

HAS 2A – Pilot A: No tendency to overcontrol. I was able to fairly precisely get to the hover point. Any time I was off, I could make an attitude change and see the results fairly quickly to get back to the point. (PR = 4)

HAS 2A – Pilot C: Total task fairly easy to perform. No display problems. (PR = 3.5)

With no explicit translational rate information or cyclic control director guidance, the SCAS was judged to be inadequate for the task:

SCAS – Pilot A: In hover mode, I had to rely on the background for fore-and-aft and lateral drift and then cross-check airspeed for fore-and-aft translation. Just by making attitude changes in the lateral axis there was a complete tendency to overshoot and go too far in one direction. In the bob-up mode, I tended to overshoot and overcontrol in all axes. My concentration was on the center of the display, and, therefore, my altitude was off. I was really aware of some pretty healthy attitude inputs that I made. (PR = 7)

SCAS – Pilot C: During the bob-up mode, position over the hover box was gross. I had a very hard time having the right attitude to even stop the thing. . . . poor height control because of workload saturation in position control. (PR = 7.5)

However, with hover and vertical augmentation, the system was judged to be adequate for the task, even with the failure of the velocity vector and cyclic director:

HAS 2A – Pilot A: In bob-up, while the concentration was high, it wasn't impossible to fly to the (hover position symbol) by making attitude changes on the aircraft. The apparent sensitivity of the aircraft translating over the ground was not so high that you couldn't control it even when there was a deviation from the desired hover point. (PR = 5)

HAS 2A – Pilot C: The missile could be launched within limits and I could return to my original hover spot fairly

readily — with a fairly high workload, though. Pretty hard to do three things. I'm surprised I did as well. As long as you didn't get large errors in position and velocity, you could pretty well keep it under control. (PR = 6.5)

Finally, with all of the hover symbols inactive, Pilot A still judged the system to be adequate with hover and vertical augmentation. In this display failure mode, only the background video was available for horizontal position information:

HAS 2A — Pilot A: As long as I was at 50 ft and I had a definite reference point in front of me, fairly close, I was able to use that information for lateral positioning. I really did use the background. As I went higher to 100 ft, I lost the reference in front of me, and I picked up a pretty healthy lateral drift. Without good attitude information, you are going to build up some high lateral drift at the higher altitudes. Airspeed provides some information on fore-and-aft drift. (PR = 6)

Turbulence Effects

The steady wind, wind shear, and turbulence simulated for this experiment in general degraded pilot ratings for the hover and bob-up task. Figures 13 and 14 demonstrate this turbulence effect as well as the inability of the display variations investigated to "wind-proof" the system. Only the hover augmentation control systems that included augmentation of the vertical axis provided an apparent insensitivity to turbulence (Fig. 11):

HAS 2A/H$_1$ — Pilot C: The aircraft took wind and turbulence quite well. (PR = 3)

Task Effects

Figure 16 compares the ratings received from Pilot A with the SCAS and Attitude Hold systems for the full mission with the average of Pilot A's ratings for the hover and bob-up task. The similarity of his ratings of the SCAS for both tasks, as well as pilot commentary, indicates that the hover and bob-up task is a dominant factor in his evaluation of the SCAS for the full mission. In contrast, the degradation of his ratings of the Attitude Hold system for the full mission indicates, according to pilot commentary, the unsuitability of this particular system for the maneuvers required during accelerating and decelerating transitions; this system was downrated primarily because of the sluggishness evident in the pitch and yaw axes.

Conclusions

A piloted simulator investigation of the effects of variations in control system characteristics and display format and logic on handling qualities for a nighttime attack helicopter mission was conducted on the Ames six-degree-of-freedom moving-base simulator facility (S.01). The following conclusions are based on the pilot evaluation data obtained from that investigation:

1. The handling qualities of the baseline control/display system are unsatisfactory without improvement for the task under consideration in this investigation.

2. Improvements in the handling qualities of the baseline system may be achieved by either control system or display modifications or both.

3. The display modifications that provide the most significant improvement in pilot rating are the increased accuracy of the velocity vector symbol drive logic and the rescaling of the hover symbology based on the characteristics of the controlled vehicle; the variations in display format investigated provided no significant improvements. The information content of the baseline display format is satisfactory for the task.

4. For the hover and bob-up task in moderate turbulence, a horizontal velocity command system and artificial augmentation of the vertical axis are required for satisfactory handling qualities.

5. A failure of the baseline pitch SCAS even with the improved hover symbology dynamics yields a system that is not adequate for the task. With the baseline SCAS, the loss of displayed cyclic control director and horizontal inertial velocity information also yields an inadequate system; a hover and vertical augmentation system with the same display failure yields handling qualities that are adequate but still unsatisfactory for the task.

In general, the single-mode SCAS represented by the baseline system is not satisfactory for the entire nighttime attack helicopter mission; the requirements for the hover, bob-up, and weapon delivery tasks are sufficiently different from those for the higher speed flight tasks that widely different controlled vehicle characteristics are necessary for these mission segments for a satisfactory system overall. Finally, the dynamics of the central hover symbology portion of the pilot's display must be designed to be compatible with the dynamic characteristics of the controlled

vehicle and the requirements of the task to ensure pilot acceptability.

References

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APPENDIX

Inertial Velocity Estimation Logic

The purpose of the complementary filter logic investigated in this experiment is to generate accurate, noise-free estimates of aircraft inertial velocity in the horizontal plane. These velocity components may then be used as variables for the display or control system to assist the pilot in reaching and maintaining a precision hover. Assuming no external guidance source, the logic includes inputs from a Doppler radar, pitch and roll attitude gyros, and longitudinal and lateral linear accelerometers. The Doppler drift velocities provide the low-frequency component of the estimated inertial velocity; the higher frequency portion of the estimate is based on approximate values of inertial acceleration.

For small values of pitch and roll attitude, the appropriate inertial accelerations may be expressed in terms of the measured linear accelerations and aircraft attitudes as:

$$\ddot{x} \doteq a_x + a_z \theta$$

$$\ddot{y} \doteq a_y - a_z \phi$$

where a_x and a_y are the accelerations as measured by body-axis mounted linear accelerometers at the aircraft center of gravity.

The filtered estimates of inertial velocity may then be expressed in general as:

$$\hat{\dot{x}} = \left[\frac{1}{Ts + 1}\right]\dot{x} + \left[\frac{TT_1 s}{(Ts + 1)(T_1 s + 1)}\right](a_x + a_z\theta)$$

$$\hat{\dot{y}} = \left[\frac{1}{Ts + 1}\right]\dot{y} + \left[\frac{TT_1 s}{(Ts + 1)(T_1 s + 1)}\right](a_y - a_z\phi)$$

The filter time constant T is selected ideally based on the relative noise characteristics of the sensors with consideration given to the filter settling time for the mission.

The above expressions were implemented for the Reference 3 experiments with some simplifications. Specifically:

1. a_x and a_y were assumed negligible with respect to the $a_z\theta$ and $a_z\phi$ terms, respectively

2. 1-g flight was assumed, that is, $a_z \doteq -g$

The value of T_1 was selected to be 10 sec and T varied from 0.1 to 10 sec over a 10-sec period from the time the hover display mode was selected by the pilot. The H_o display, therefore, includes the following logic for the velocity vector:

$$(\hat{x})_{H_O} = \left[\frac{1}{T(t)s + 1}\right]\dot{x} - g\left\{\frac{10T(t)s}{[T(t)s + 1](10s + 1)}\right\}\theta$$

$$(\hat{y})_{H_O} = \left[\frac{1}{T(t)s + 1}\right]\dot{y} + g\left\{\frac{10T(t)s}{[T(t)s + 1](10s + 1)}\right\}\phi$$

No noise was simulated in any of the filter inputs; the purpose of the experiment included only an assessment of the effects of the filter characteristics on handling qualities, and the effects of noise were judged to be outside the scope of the investigation.

In the presence of wind and wind shear, the lack of linear accelerometer data in the Reference 3 implementation results in a generally incorrect dynamic response of the estimated velocities to the changing wind conditions. In addition, even assuming the Doppler velocities and high-frequency inertial acceleration estimates to be perfect, the selection of the values of T and T_1 to be identical at 10 sec in the steady-state results in a transfer function of the estimated velocity to the actual velocity of:

$$\frac{(\hat{x})_{H_O}}{\dot{x}} = \frac{(\hat{y})_{H_O}}{\dot{y}} = \frac{s^2 + 2(0.5)(0.1)s + (0.1)^2}{(s + 0.1)^2}$$

This relationship implies significant errors of the estimated velocity in both magnitude and phase angle in a frequency region of importance to the pilot; specifically, the above system exhibits a 6 dB droop at a frequency of 0.1 rad/sec and a 24° phase lag at 0.05 rad/sec.

As an alternative to the Reference 3 logic, the following modifications were made for the H_1 and S_1 displays:

1. The terms a_x and a_y were retained in the expressions for inertial acceleration.

2. The filter time-constant T was set at a constant value of 3.33 sec to reduce the errors induced by the 1-g flight assumption. This value corresponds to the heave damping time constant of the unaugmented aircraft in hover.

3. The value of T_1 remained unchanged at 10 sec. Assuming perfect inputs as before, this selection of time constants results in:

$$\frac{(\hat{x})_{H_1,S_1}}{\dot{x}} = \frac{(\hat{y})_{H_1,S_1}}{\dot{y}}$$

$$= \frac{s^2 + 2(0.88)(0.17)s + (0.17)^2}{(s + 0.1)(s + 0.3)}$$

which minimizes the errors in gain and phase evident in the Reference 3 implementation; the mid-frequency droop is reduced to 2 dB and the maximum phase lag is approximately 12°.

As a result of the above modifications, the filter logic implemented for the H_1 and S_1 formats is:

$$(\hat{x})_{H_1,S_1} = \left[\frac{1}{3.33s + 1}\right]\dot{x}$$
$$+ \left[\frac{33.3s}{(3.33s + 1)(10s + 1)}\right](a_x - g\theta)$$

and

$$(\hat{y})_{H_1,S_1} = \left[\frac{1}{3.33s + 1}\right]\dot{y}$$
$$+ \left[\frac{33.3s}{(3.33s + 1)(10s + 1)}\right](a_y + g\phi)$$

TABLE 1. Body-Axis Stability and Control Derivatives (V = 0).

	u, m/sec (ft/sec)	v, m/sec (ft/sec)	w, m/sec (ft/sec)	p, rad/sec	q, rad/sec	r, rad/sec	A_{1_S}, deg	B_{1_S}, deg	θ_O, deg	θ_{TR}, deg
X, m/sec² (ft/sec²)	-0.0185	0.004	0.0279	-0.44 (-1.45)	0.42 (1.39)	-0.11 (-0.37)	-0.009 (-0.03)	0.1874 (0.6147)	0.1014 (0.3328)	0.0 (0.0)
Y, m/sec² (ft/sec²)	0.0	-0.06	-0.0016	-0.4460 (-1.463)	-0.4450 (-1.46)	0.2182 (0.7159)	0.1898 (0.6226)	0.006 (0.019)	-0.0082 (-0.0268)	0.061 (0.20)
Z, m/sec² (ft/sec²)	-0.0194	-0.036	-0.30	-0.0024 (-0.08)	0.0956 (0.3137)	0.762 (2.5)	0.0 (0.0)	0.0182 (0.0596)	-1.391 (-4.562)	0.0 (0.0)
L, rad/sec²	0.0 (0.0)	-0.0778 (-0.0237)	-0.003 (-0.001)	-2.86	-1.2	0.0292	0.7676	0.04	-0.1	0.06
M, rad/sec²	0.0082 (0.0025)	0.0003 (0.0001)	-0.00043 (-0.00013)	0.22	-0.5092	0.03	0.008	-0.1242	-0.0014	-0.0022
N, rad/sec²	0.0 (0.0)	0.0108 (0.0033)	0.007 (0.002)	-0.1883	-0.15	-0.4409	0.013	0.003	0.1618	-0.08

TABLE 2.   Hover Augmentation System Transfer Functions.

	$\dfrac{\dot{x}}{\delta_e} = \left\{\dfrac{B_{1_s}}{\delta_e}\right\} \cdot \dfrac{\dot{x}}{B_{1_s}} \sim$ m/sec/cm	$\dfrac{\dot{y}}{\delta_a} = \left\{\dfrac{A_{1_s}}{\delta_a}\right\} \cdot \dfrac{\dot{y}}{A_{1_s}} \sim$ m/sec/cm
HAS 1 (IACVH)	$\left\{-\dfrac{1.97(s+0.5)}{s}\right\} \cdot \dfrac{1.22}{(s+0.5)(s+2.0)^2}$	$\left\{\dfrac{0.63(s+0.5)}{s}\right\} \cdot \dfrac{7.62}{(s+0.5)(s+2.0)^2}$
HAS 2 (IVC)	$\left\{-1.97\right\} \cdot \dfrac{1.22}{(s+0.5)(s+2.0)^2}$	$\left\{0.63\right\} \cdot \dfrac{7.62}{(s+0.5)(s+2.0)^2}$
HAS 3 (IVCPH)	$\left\{-\dfrac{1.97(s+0.5)}{s}\right\} \cdot \dfrac{1.22s}{(s+0.5)^2(s+2.0)^2}$	$\left\{\dfrac{0.63(s+0.5)}{s}\right\} \cdot \dfrac{7.62s}{(s+0.5)^2(s+2.0)^2}$

TABLE 3.   Control Systems — Generic Characteristics.

CONTROL SYSTEM	PITCH	ROLL	YAW	VERTICAL
AAH SCAS	Pitch rate, attitude, and airspeed feedback; control quickening	Shaped roll rate feedback; control quickening	Washed-out yaw rate feedback; control quickening	No augmentation
AAH Attitude Hold	Control quickening removed from SCAS	Control quickening removed from SCAS	Same as SCAS with different shaping of yaw rate feedback	No augmentation
HAS 1	IACVH	IACVH	RCHH	No augmentation
HAS 2	IVC	IVC	RCHH	No augmentation
2A	IVC	IVC	RCHH	RCAH
HAS 3	IVCPH	IVCPH	RCHH	No augmentation
3A	IVCPH	IVCPH	RCHH	RC
3B	IVCPH	IVCPH	RCHH	RCAH

TABLE 4. Control Force Characteristics.

CHARACTERISTIC	CONTROLLER			
	LATERAL	LONGITUDINAL	DIRECTIONAL	COLLECTIVE
Force gradient, N/cm (lb/in.)	0.5 (0.3)	0.9 (0.5)	12.3 (7.0)	Adjustable friction
Breakout force, N (lb)	5.8 (1.3)	4.5 (1.0)	31.2 (7.0)	Adjustable friction
Travel, cm (in.)	±11.4 (±4.5)	±12.7 (±5.0)	±7.0 (±2.75)	0-30.5 (0-12)

TABLE 5. Display Gains (Hover and Bob-up Modes).

GAIN PARAMETER[a]	DISPLAY					UNITS[b]
	H_0	H_1			S_1	
		SCAS	ATTITUDE HOLD	HAS		
$K_{\dot{x}}$	6.6 (2.0)	3.3 (1.0)	3.3 (1.0)	3.3 (1.0)		°/m/sec (°/ft/sec)
$K_{\dot{y}}$	6.6 (2.0)	3.3 (1.0)	3.3 (1.0)	3.3 (1.0)		°/m/sec (°/ft/sec)
T_θ	10.0	50.0	10.0	2.5	SEE	sec
K_θ	0.763	1.89	0.350	0.225	H_1	°/deg
T_ϕ	10.0	6.67	3.7	2.5	GAINS	deg
K_ϕ	0.763	0.760	0.520	0.225		°/deg
$K_x{}^c$	1.49 (0.4545)	0.7 (0.2)	0.7 (0.2)	0.7 (0.2)		°/m (°/ft)
$K_y{}^c$	1.49 (0.4545)	0.7 (0.2)	0.7 (0.2)	0.7 (0.2)		°/m (°/ft)

[a]Maximum deflection of hover symbols is ±15°.

[b]The degree symbol (°) denotes degree of arc subtended at pilot's eye.

[c]H_1 and S_1 displays use nonlinear position scaling technique defined in the text.
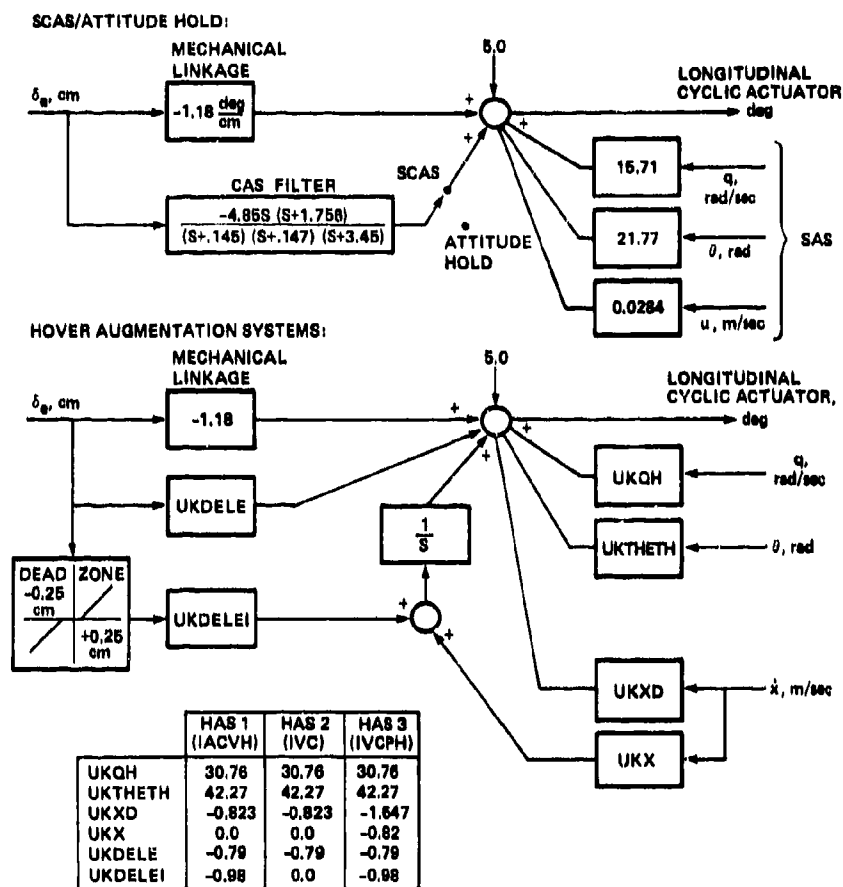
Figure 1.   Advanced helicopter control systems — pitch.

SCAS/ATTITUDE HOLD:

MECHANICAL LINKAGE

δ_a, cm

$0.81 \frac{deg}{cm}$

-1.75

LATERAL CYCLIC ACTUATOR, deg

CAS FILTER

$\frac{0.357S (S+2.3)}{(S+0.2)(S+0.2)(S+0.769)}$

SCAS

ATTITUDE HOLD

SAS

$\frac{-1.9(S+2.3)}{(S+0.2)}$ ← p, rad/sec

HOVER AUGMENTATION SYSTEMS:

MECHANICAL LINKAGE

δ_a, cm

0.81

-1.75

LATERAL CYCLIC ACTUATOR, deg

UKDELA

$\frac{1}{S}$

UKPH ← p, rad/sec

UKPHIH ← ϕ, rad

DEAD ZONE
-0.25 cm
$+0.25$ cm

UKDELAI

UKYD ← $\dot{y}$, m/sec

UKY

	HAS 1 (IACVH)	HAS 2 (IVC)	HAS 3 (IVCPH)
UKPH	-2.0	-2.0	-2.0
UKPHIH	-7.26	-7.26	-7.26
UKYD	-0.1053	-0.1053	-0.2106
UKY	0.0	0.0	-0.13
UKDELA	-0.18	-0.18	-0.18
UKDELAI	0.31	0.0	0.31

Figure 2. Advanced helicopter control systems — roll.

Figure 3. Advanced helicopter control systems — yaw, V < 50 knots.
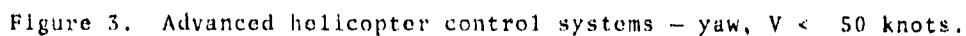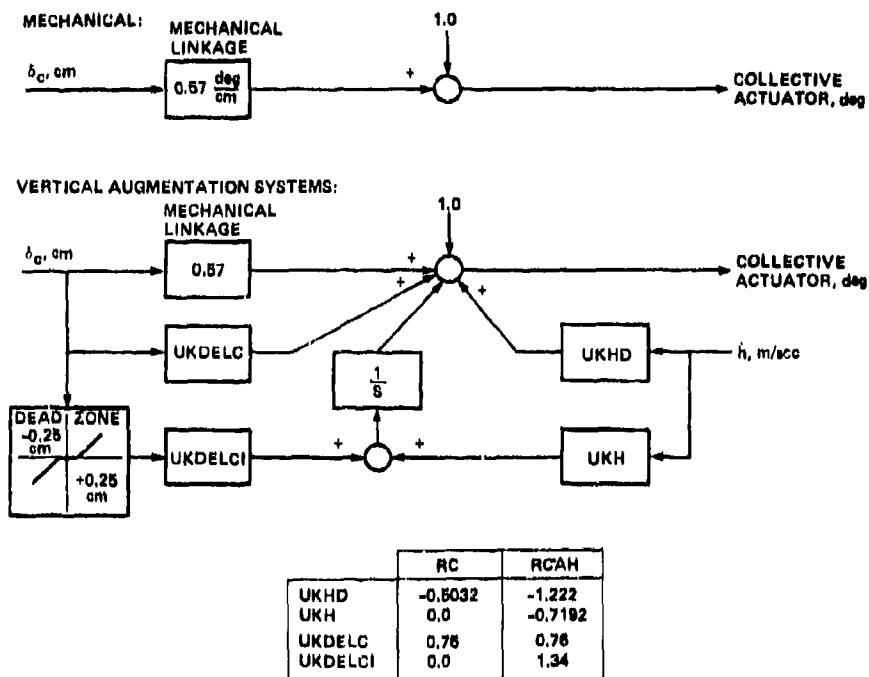
Figure 4. Advanced helicopter control systems — collective.
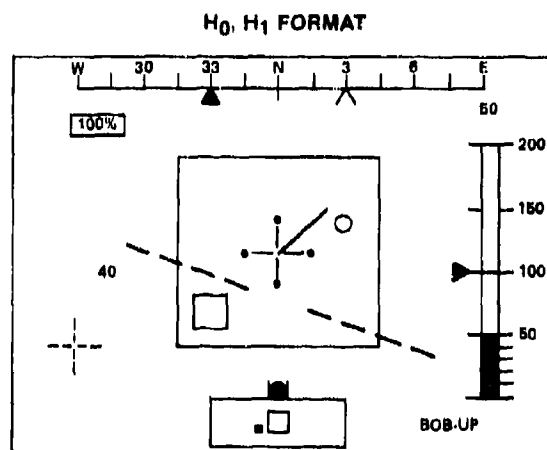
Figure 5. Baseline display format.
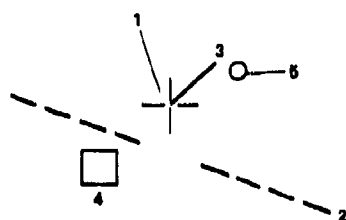
SYMBOL	INFORMATION
1. Aircraft reference	Fixed reference for horizon line, velocity vector, hover position, cyclic director, and fire control symbols
2. Horizon line (cruise mode only)	Pitch and roll attitude with respect to aircraft reference (indicating nose-up pitch and left roll)
3. Velocity vector	Horizontal Doppler velocity components (indicating forward and right drift velocities)
4. Hover position	Designated hover position with respect to aircraft reference symbol (indicating aircraft forward and to right of desired hover position)
5. Cyclic director	Cyclic stick command with respect to hover position symbol (indicating left and aft cyclic stick required to return to designated hover position)

(a) Central symbology.
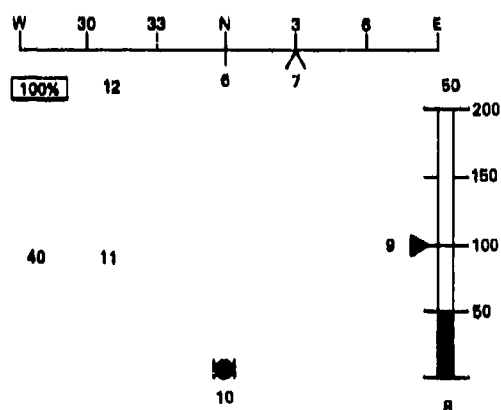
SYMBOL	INFORMATION
6. Aircraft heading	Moving tape indication of heading (indicating North)
7. Heading error	Heading at time bob-up mode selected (indicating 030)
8. Radar altitude	Height above ground level in both analog and digital form (indicating 50 ft)
9. Rate of climb	Moving pointer with full-scale deflection of ±1,000 ft/min (indicating 0 ft/min)
10. Lateral acceleration	Inclinometer indication of side force
11. Airspeed	Digital readout in knots
12. Torque	Engine torque in percent

(b) Peripheral symbology.
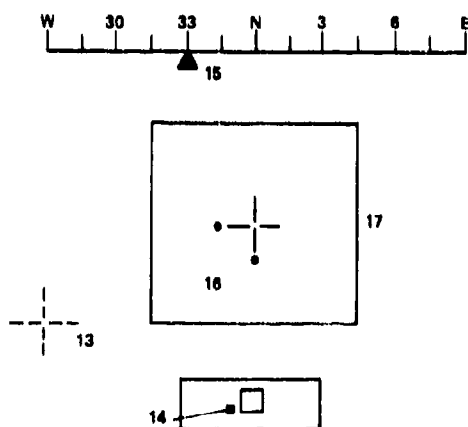
SYMBOL	INFORMATION
13. Cued line of sight	Overlays designated target position on background video when target is in display field of view
14. Coarse target location	Designated target position with respect to display field of view (inner rectangle) and sensor limits (outer rectangle)
15. Target bearing	Designated target bearing (indicating 330° or 30° to left of current heading)
16. Target location dots	Illumination of two adjacent dots indicates display quadrant in which designated target is located
17. Missile launch constraints	Limits with respect to aircraft reference for successful weapon lock-on to designated target

(c) Fire control symbology.

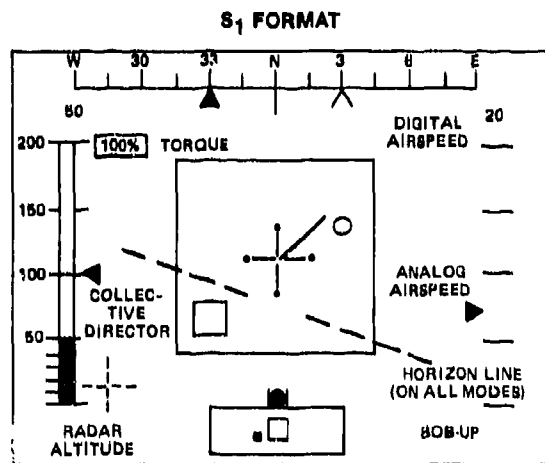Figure 6. Display mode symbology.

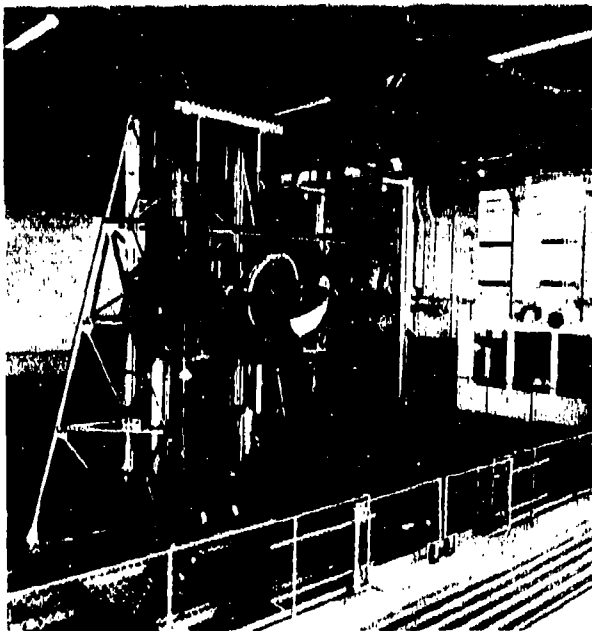**S₁ FORMAT**

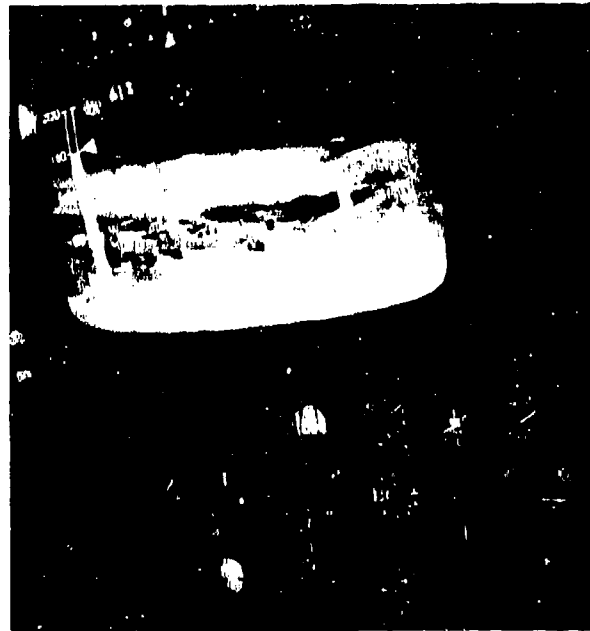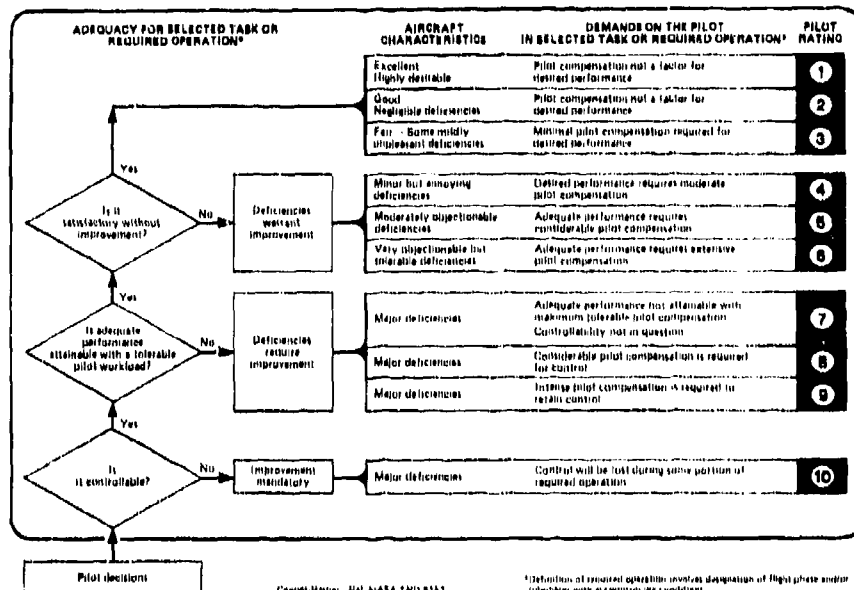Figure 7. Alternative display format.

Figure 8. NASA-ARC S.01 simulator.

Figure 9. S.01 cockpit arrangement.

HANDLING QUALITIES RATING SCALE

Figure 10. Cooper-Harper pilot rating scale.

DEFINITIONS FROM TN-D-5153

COMPENSATION

The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

HANDLING QUALITIES

Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role.

MISSION

The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase.

PERFORMANCE

The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task.)

ROLE

The function or purpose that defines the primary use of an aircraft.

TASK

The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

WORKLOAD

The integrated physical and mental effort required to perform a specified piloting task.
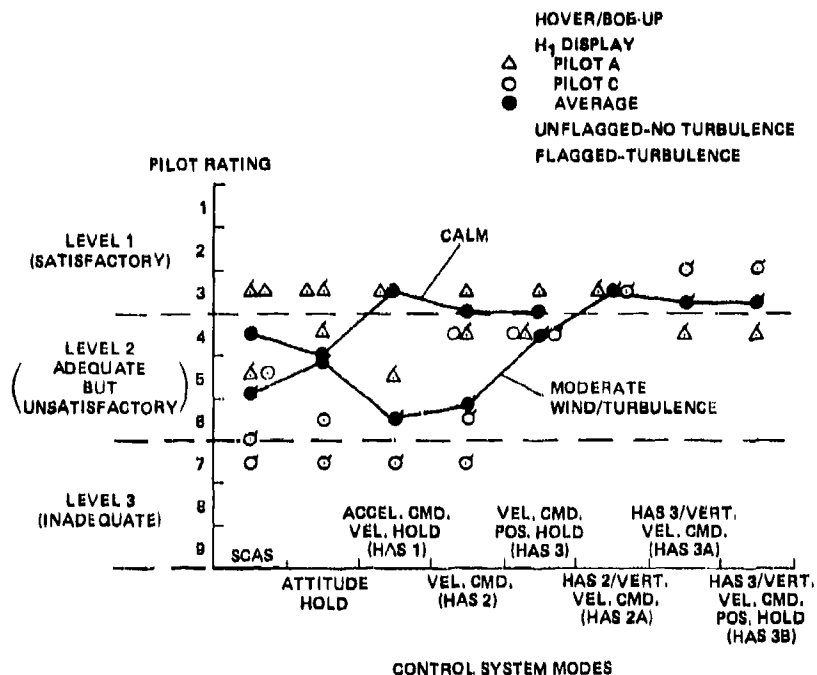
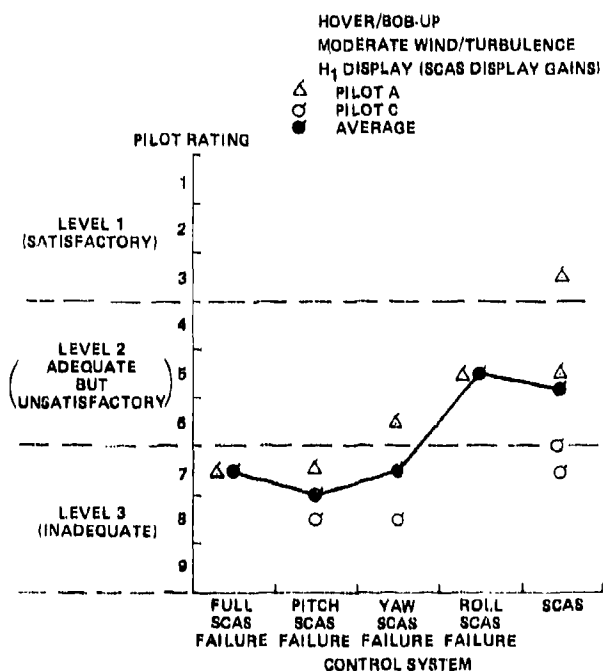Figure 11. Pilot rating results – control system effects.

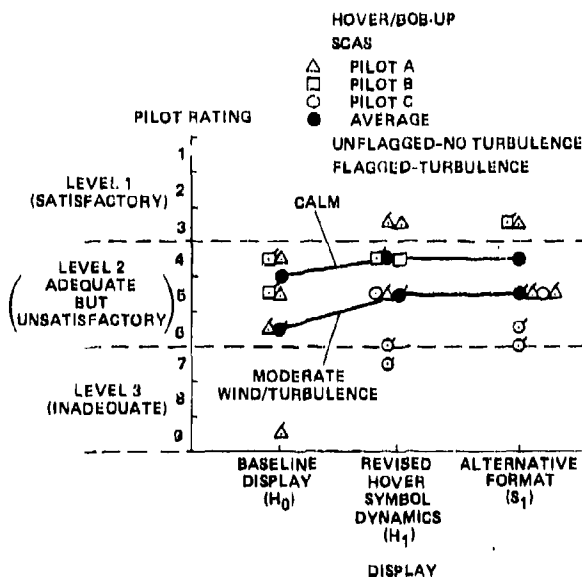Figure 12. Pilot rating results – control system failures.

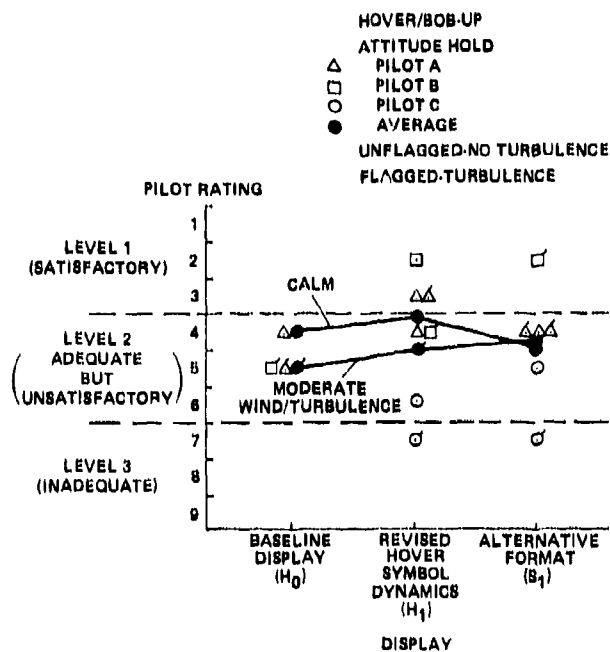Figure 13. Pilot rating results – display effects (SCAS).

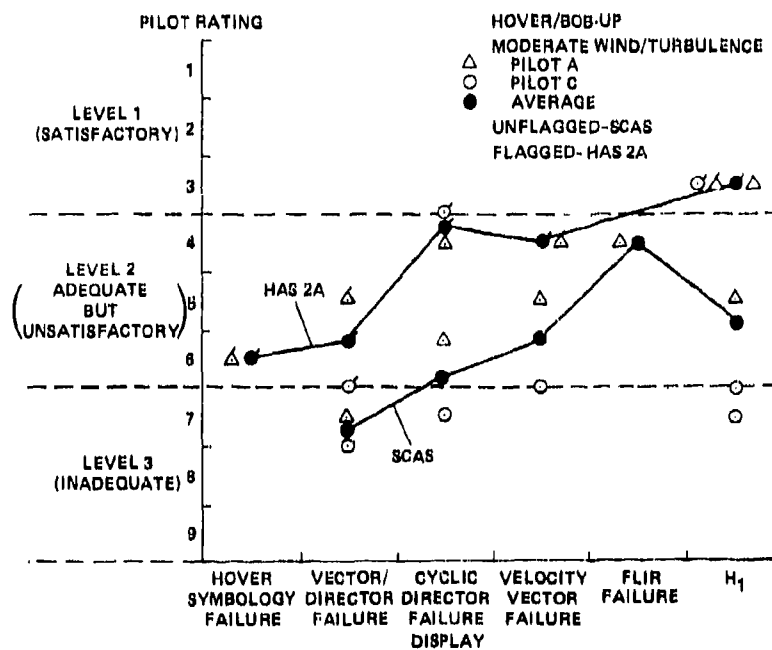Figure 14. Pilot rating results – display effects (Attitude Hold).

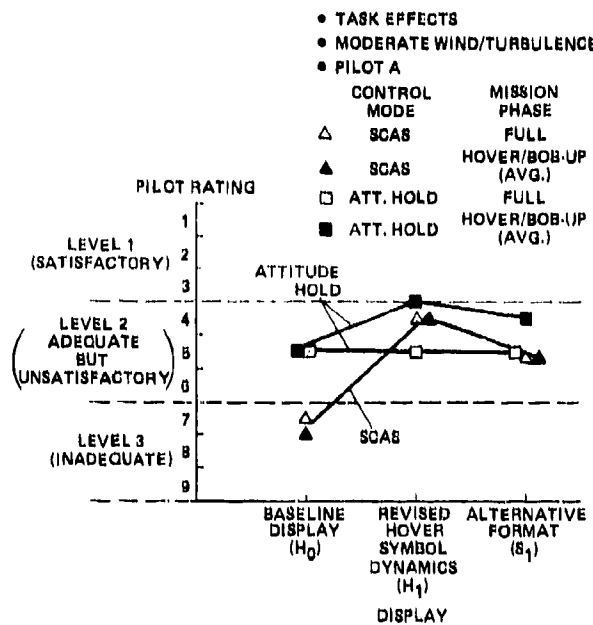Figure 15. Pilot rating results – display failures.

Figure 16. Pilot rating results — task effects.

80-28-24